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Shape and Layout Understanding Method Using Brain Machine Interface for Idea Creation Support System

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Abstract

In conceptual design for an attractive product, the visualization of Kansei value as requirements and the realization of its value for creating product ideas are desired. Therefore, the Idea Creation Support System (ICSS)—for an idea creation with Kando understanding process through Word Of Mouth (WOM) effectiveness—has been developed. ICSS has consisted of two understanding processes, i.e., problem and Kando understanding processes. However, ICSS does not include shape and layout understanding process—which is grasping the imagined topology of mind as requirement—which is most important process as for mechanical products. In this study, we propose the shape and layout understanding method which consisted of SIMP method as a topology optimization and Kansei information understanding of topology using Electroencephalography (EEG) through Brain Machine Interface (BMI), and also discuss the system configuration of ICSS with shape and layout understanding method.

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Keywords: *Kansei value; Conceptual design; Topology optimization; BMI; EEG; Idea Creation Support System*

1. Introduction

The Kansei initiative of the Ministry of Economy, Trade and Industry in Japan has proposed necessity of the creation of Kansei as 4th value axis which overcomes advanced function, reliability, and low cost[1]. For realization of this proposal, a visualization of Kansei value as requirements—which customers notice based on emotional and surprise experiences looked at a product, took it in hand, or used it—is expected in conceptual design. It is necessary

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to create an idea for a product which realizes both requirements of this visualized Kansei value and conventional requirements which consists of needs, technology, and constraints via not trade-off analysis but contradiction solving. From this background, conceptual design process supporting methodologies have been studied by many researchers in various application areas in research of creativity or engineering design[2-12]. For supporting an innovative creation, Hasegawa et al. defined the creative thinking process as the creation of a new combination of existing elements, which is believed in having an edge on others, for user― designer or development team ―itself[11]. And, it needs to mobilize user's knowledge and know-how, additionally, other things beyond them. The solution was drawn on from its process is defined as the design solution with an innovative creation. Moreover, its process demands to be supported with no depending on user's sensibility or knowledge. To satisfy these requirements, Hasegawa et al. have developed the thinking process of the Creative and inventive Design Support System (CDSS), and have evaluated the validation of CDSS's process by using quality engineering[11]. However, requirement understanding methodologies in order to create new value like Kansei value through customer experience is not clearly defined in a conceptual design support process.

For this challenge, Sato et al. have proposed the process of considering the customer's Kando in the problem understanding of CDSS[12]. Kando is Japanese word for the simultaneous feelings of deep satisfaction and excitement. Sato et al. have explained the Kando definition through the emotional design and AIDEES model for a consumer behavior understanding[13-15]. Kando has been defined as "Kando is generated by the interaction of the behavioural level and the reflective level, when a favorable experience with a surprise is larger than a past experience into the re-evaluated process"[15]. Moreover, the AIDEES model[14] as a consumer behavior model has been modelled with "Consumers use care with things, attend to them, desire, experience their brand, become enthusiastic through their experience, and consumer's Kando is told to consumers and shared". When sharing, information on products is given by Word-Of-Mouth (WOM) communication. Thus, an attractive product is things where customers did Kando through consumer behavior. Kando is generated through experience as shown in Fig. 1. Since Kando has been generated by an experience with a surprise, Sato et al. have considered that Kando, which the consumer by oneself has not noticed, can be obtained by extracting a reason of surprise, an element of surprise, an element of experience, and a past experience for comparison[15]. These elements and reasons are dealt in as the Kando requirement, and it is one of the elements should be taken into consideration in a requirement definition and analysis phases. From the above consideration and discussion, Sato et al. have proposed the Idea Creation Support System (ICSS) ―for an idea creation to the Kando understanding process through WOM effectiveness[12,15,16]. And, ICSS has consisted of problem understanding and Kando understanding processes, and requirements-solutions' Quality Function Deployment (QFD) matrix for visualization of these relationship and contradiction. And, obtained requirement-solution's contradiction via QFD matrix is able to be solved by using CDSS.

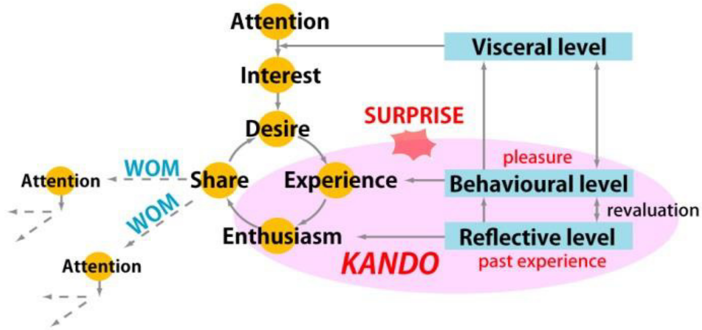


Fig. 1. Definition of Kando through the emotional design and AIDEES model

On the other hand, requirement specification for mechanical products are described by documents and drafting like idea sketches and technical drawings. However, ICSS could aid to visualize Kando requirement as Kansei value, but without visualizing Kansei value of shape and layout represented by sketch and drawing. Therefore, we proposed the shape and layout understanding process which grasps the imagined topology to mind as requirement, and included its process to ICSS as shown in Fig. 2.

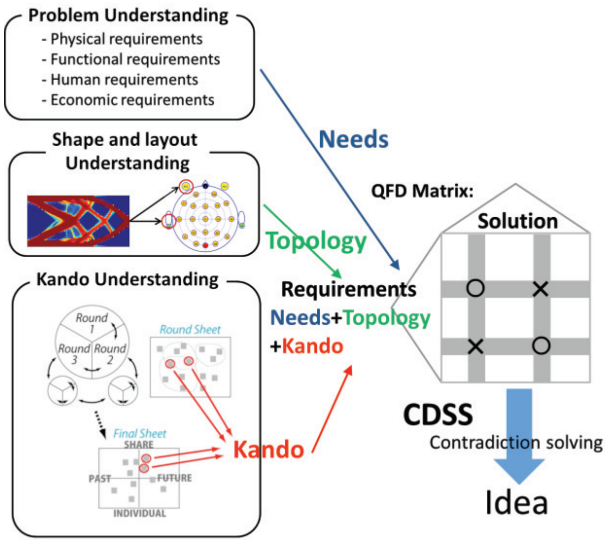


Fig. 2. Idea Creation Support System included shape and layout understanding

In this study, we developed the shape and layout understanding method which consisted of Solid Isotropic Microstructure with Penalization (SIMP) method[17-19] as a topology optimization and Kansei information understanding of topology using Electroencephalography (EEG) through Brain Machine Interface (BMI), and also discuss the system configuration of ICSS with shape and layout understanding method.

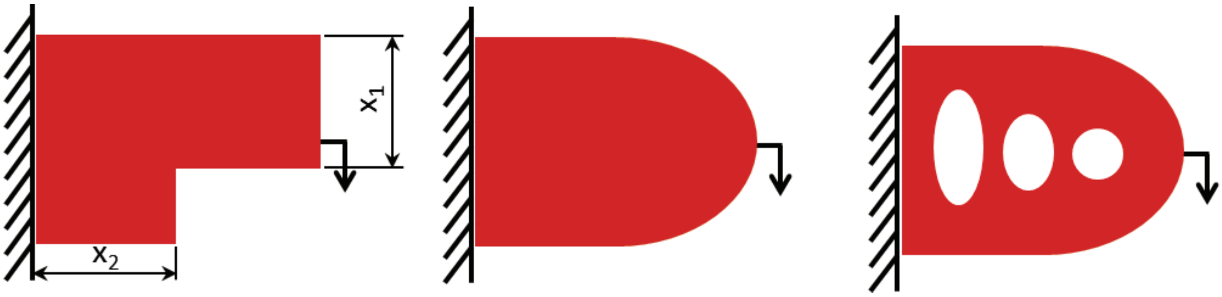
This paper is organized in the following manner. Chapter 2 explains outline of the shape and layout understanding process, and proposes the topology optimization based on physical conditions using EEG through BMI, respectively. Chapter 3 provides the creation result of topology as requirement via proposed method and verifies the obtained topology as requirement by using SD analysis result. Chapter 4 provides some brief conclusions.

Nomenclature

ICSS	Idea Creation Support System
CDSS	Creative and inventive Design Support System
WOM	Word Of Mouth
QFD	Quality Function Deployment
EEG	Electroencephalography
BMI	Brain Machine Interface
SIMP	Solid Isotropic Microstructure with Penalization

2. Shape and layout understanding process for grasping Kansei value

To develop the shape and layout understanding process, we introduced a topology optimization methodology[17-22]. Topology optimization is one of the structural optimization methodologies for the mechanical and the architecture product design. Especially, its optimization methodology is used in basic design from renewing shape and layout (number, position and size of void) concurrently as shown in Fig. 3. And also, topology optimization methodology to conceptual design is applied by many researchers for making emergent and creative structure[23,24]. For examples, Kawano et al. have proposed the design idea generation support system for the facade design of the office building. Its support system realized awakening for a creation of the facade design through the Kansei evaluation for impression of form elements using Interactive Differential Evolution with Score (IDES)[23]. As for mechanical product, Sato et al. have developed the emergent design system using the topology optimization method in a structural design problem[24]. Its emergent design system is a design system based on concept of emergence, and can derive diverse solutions. However, it is necessary to choose the design solution suitable for own Kansei from diverse design proposals by its emergence system. Thus, it is not necessarily to express the design solution which represented the image of own mind from the reflection level as a conceptual design.



(a) Size optimization (b) shape optimization (c) Topology optimization

Fig. 3. Structural optimization

In this study, for grasping the imagined shape and layout of own mind as requirement, we propose topology optimization by using brain waves information as controlling topology parameters. In order to grasp the Kansei information for shape and layout, EEG is got as information on brain waves by BMI. Furthermore, the topology, where the physical characteristic was fulfilled, is created automatically by inputting EEG data into topology optimization as topology parameters. In Section 2.1, SIMP method which is a topology optimization methodology is outlined, and also EEG data and the measurement method by BMI are explained in Section 2.2. Moreover, the renewal method for an elastic modulus using EEG and the development of the discriminant function for getting the Kansei information are described from Section 2.3 to 2.5.

2.1. SIMP method for topology optimization

The topology representation of a mechanical structure has applied to SIMP method[18,19]. In SIMP method, topology representation has been expressed by distribution of the composite layers' material which included the void as one layer. And also, the law of mixtures generally has applied to the composite material. In case of two layers (solid and gas), the elastic modulus of the mechanical structure is shown artificially as follows.

$$E_{\boldsymbol{\rho}} = \boldsymbol{\rho}^{p} E_1 + \left(1 - \boldsymbol{\rho}^{p}\right) E_2, \tag{1}$$

where $\boldsymbol{\rho} \in [0,1]$ is density vector without void layer. E_1 and E_2 denote elastic modulus of these materials, respectively. $p > 1$ is penalty parameter for middle density into final structural design. Additionally, void layer is modelled by $E_2 = 0$. Moreover, modification method of density vector $\boldsymbol{\rho}$ as design variables applied Sequential Linear Programming (SLP) method.

As for the physical characteristic, the stiffness of mechanical structure is maximized within the assigned volume. This topology optimization is minimized by using the mean compliance $f(\boldsymbol{\rho})$ as an objective as follows.

$$f(\boldsymbol{\rho}) = \int_{\Gamma_1} \boldsymbol{F} \cdot \boldsymbol{u}(\boldsymbol{\rho})\, d\Gamma_1, \tag{2}$$

where $\boldsymbol{F}$, $\boldsymbol{u}$, and Γ_1 denote force vector, displacement vector, and plane of loading, respectively.

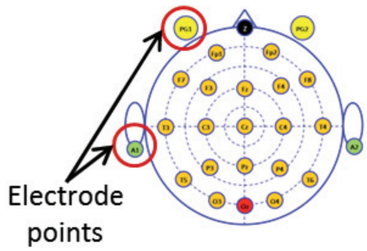
2.2. Measurement for EEG information

Brain waves are the electric signals of the neuron propagated by the input and output to the deeper layers of the cerebral cortex, and the electric potential curve is EEG. The cerebral neurons receive two signals, i.e., excitation and modulated signals, and generate various patterns of the electric signal. An electric change, repeated in a constant rhythm in the electric potential curve of brain waves, is called the posterior basic rhythm[25]. This rhythm mainly is frequency around 10Hz of alpha wave in Table 1. Brain waves consist of frequency components, and also EEG can be classified into five frequency bands, i.e., Delta, Theta, Alpha, Beta, and Gamma as shown in Table 1. The method of brain waves measurement has generally two kinds, an invasiveness type and a noninvasive type. In this study, Mindset (NeuroSky Co.) which is a simple brain waves measuring device as BMI of a noninvasive type was adopted. Because, its device uses from safety and convenience, although a noninvasive type has a problem from which brain waves change with the influences of a skull etc. The location of scalp electrodes was applied the international 10-20 system―which is an internationally recognized method in the context of an EEG test or experiment. As shown in Fig. 4, the potential of the electrode of an arm part to the left frontal lobe and the standard potential from the electrode of the pad part of a left ear were measured, respectively. Brain waves were calculated from the potential difference between these two electrode points. Additionally, the information on eight kinds of frequency bands (see in Table 1) was obtained from the acquired original brain waves.

Table 1. EEG classification

Brainwave type	Frequency range [Hz]	Mental states and conditions
Delta δ	0.5 to 2.75	Deep, dreamless sleep, non-REM sleep, unconscious
Theta θ	3.5 to 6.75	Intuitive, creative, recall, fantasy, imaginary, dream
Low Alpha α	7.5 to 9.25	Relaxed, but not drowsy, tranquil, conscious
High Alpha α	10.0 to 11.75	
Low Beta β	13.0 to 16.75	Formerly SMR, relaxed yet focused, integrated
High Beta β	18.0 to 29.75	Thinking, aware of self & surroundings, alertness, agitation
Low Gamma γ	31.0 to 39.75	High order brain activity
High Gamma γ	41.0 to 49.75	

(a) Mindset for BMI



(b) Measuring point

Fig. 4. BMI measurement device

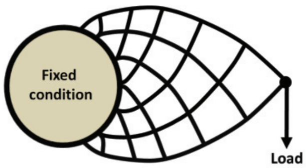
2.3. Topology optimization using EEG

In order to create a mechanical structure's topology as a requirement, this section describes how to increase or decrease an elastic modulus which is part of the material attributes of mechanical structure by using EEG based on the SIMP method. In the SIMP method, a final structural topology differs with the renewal method of an elastic modulus, especially a penalty parameter. For example, the cantilever's optimal structure becomes a topology of a net-shape like the theoretical solution of Michell's truss theory[26] in Fig. 5 (a). However, by renewing an elastic modulus drastically or slowly, various topologies—which consist of the two thick beams (an external layout) and various layouts (an inner layout)—are drawn as shown in Fig. 5 (b). This SIMP method's characteristic becomes a big problem, called a grayscale problem, in structure optimization research area. However, this characteristic is an attractive in order to understand shape and layout under the situation which fulfilled the physical conditions through EEG data. Therefore, we focused attention on the advantage which can change a final topology flexibly via SIMP method.

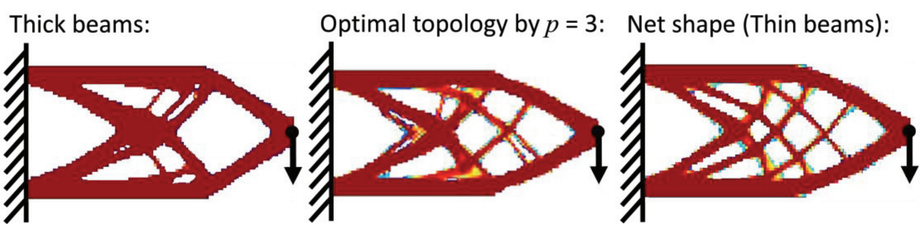
In this study, the elastic modulus' constructive formulation (see Eq. (1)) of the SIMP method is extended to Eq. (3). Four Kansei information obtained from BMI, i.e., "Excitation and Modulation" and "Increase and Decrease", are inputted for the feedback to the penalty parameter p and the density function $\boldsymbol{\rho}_i$ by using parameters r and s in Eq. (3), respectively. Specifically, viewing the progress topology of the optimization process, on-line measurement of the brain waves is carried out in a cycle of 1 second using BMI. Through distinction of the EEG data based on the discriminant function, when the Kansei information for this progress topology is judged as "Excitation", 1 is added to parameter r, and -1 is inputted when judged as "Modulation" to Parameter r. In the same way, in "Increase", 0.02 is added, and in "Decrease", -0.02 is inputted at parameter s, respectively. In addition, since the hole opens drastically when the value of the penalty parameter p became large, the Kansei information on this case was considered as "Excitation (contrary of Modulation)". On the other hand, since the value of the penalty parameter p needs to make smaller in order to modulate this case, Kansei information was considered as "Modulation". Moreover, "Increase and Decrease" were used in order to give the same effect to the density function $\boldsymbol{\rho}_i$. The values of these parameters are determined after conducting preparatory experiments.

$$\mathrm{E}_{\boldsymbol{\rho}_i} = \left(\boldsymbol{\rho}_i^{p+\mathrm{r}} + \mathrm{s}\right)E_1 + \{1 - \left(\boldsymbol{\rho}_i^{p+\mathrm{r}} + \mathrm{s}\right)\}E_2, \tag{3}$$

where, parameter r and s denote an input parameter to give Kansei information as "Excitation and Modulation" to a density function via a penalty parameter, an input parameter for reflecting Kansei information as "Increase and Decrease" in a density function directly, respectively. Additionally, i denotes element number of Finite Element Method.



(a) Theoretical solution of Michell's truss



(b) Various structural layouts inside topology by SIMP

Fig. 5. Topology of mechanical structure based on physical conditions for cantilever beam

2.4. Development of the discriminant function for getting the Kansei information from EEG data

This section describes how to create the linear discriminant function (see Eq. (4)) for getting Kansei information, i.e., "Excitation and Modulation" and "Increase and Decrease", from EEG data. First, the linear discriminant function is created for creation of a topology as requirement. In order to create the discriminant function of the Kansei information on excitation, modulation, increase, and decrease, brain waves are measured on condition of following.

- Measure brain waves in a quiet indoor place,
- Measure brain waves under a conscious of an excitation and a modulation, respectively,
- See the optimal topology of Fig. 5 (b), and measure brain waves under a conscious of an increase and a decrease in the volume of a beam, respectively.
- Measurement time is 5 seconds,
- After 10 seconds recess, measure brain waves under a conscious of other situation.

Additionally, BMI of a noninvasive type tends to be influenced by the exteriors, such as a noise. Thus, if a spiking phenomenon occurs, we processed as a noise.

$$\boldsymbol{Y} = a\boldsymbol{X}_{\delta} + b\boldsymbol{X}_{\theta} + c\boldsymbol{X}_{l\alpha} + d\boldsymbol{X}_{h\alpha} + e\boldsymbol{X}_{l\beta} + f\boldsymbol{X}_{h\beta} + g\boldsymbol{X}_{l\gamma} + h\boldsymbol{X}_{h\gamma} + \boldsymbol{Z} \tag{4}$$

where, a, b, c, d, e, f, g, and h denote coefficients for the linear discriminant function, respectively. X_i and Z denote value of each frequency bands of EEG, and intercept. Y indicates the approximate value of a discriminant result.

The measurement result of brain waves by BMI was shown in Table 2. This result was the result of measuring each Kansei information by 3 times, respectively. From Table 2, compared with the case of modulation, in the case of excitation, Low Beta, High Beta, and Low Gamma showed the high values, and Low Alpha and High Alpha showed the low values. By the same token, compared with the case of excitation, in the case of modulation, High Alpha showed the high values, and Low Beta, High Beta, and Low Gamma showed the low values. From this result, we have confirmed that a big response in the case of excitation was looked at by the high frequency band, and a big response in the case of modulation was looked at by the low frequency band, respectively. Moreover, the case of the decrease showed the big values with all the values compared with the case of the increase. As mentioned above, we have confirmed that EEG data with the feature based on subject's Kansei value could be measured. From this consideration, we judge that a subject's Kansei value can be expressed by creating a discriminant function.

In this study, the discriminant function was created using all the EEG data obtained by this measurement. Using calculated discriminant function, we believe that the discriminant function can be extracting the feature of four Kansei information. The EEG data, obtained by on-line measurement, can be discriminated using approximate value Y of the created discriminant function, and elastic modulus of topology optimization process can be renewed by inputting to the parameters r and s in Eq. (3).

Table 2. Measurement data of EEG from BMI device [mV]

	Trial	δ	θ	Low α	High α	Low β	High β	Low γ	High γ
Excitation	1	240	90	10	21	22	32	11	8
Excitation	2	216	68	49	22	19	19	21	13
Excitation	3	330	52	8	10	19	19	37	10
Modulation	4	166	83	21	59	8	13	7	26
Modulation	5	52	24	6	88	5	15	7	33
Modulation	6	43	13	13	46	3	3	1	6
Decrease	7	1317	1099	155	317	133	280	224	1111
Decrease	8	1921	1246	303	1105	160	318	446	1197
Decrease	9	640	3090	127	746	162	314	289	1629
Increase	10	244	212	87	127	55	60	51	267
Increase	11	242	298	64	122	58	59	72	273
Increase	12	271	158	47	147	69	74	56	224

2.5. Inverse approach of topology optimization process for progress topology with dissatisfaction

The optimization process is made to go back, in case of a dissatisfaction of the progress topology and when a distinction of EEG data is unsuitable. Specifically, if dissatisfaction is memorized to a progress topology, a subject's EEG data will be in a deep concentration situation. As for this situation, theta, low beta and high beta of brain-waves show a value higher than the normal concentration status. By the shape and layout understanding method, when the EEG data of this status is obtained, it distinguishes that it is dissatisfied. And, in order to resume topology optimization, progress topology, density function, and penalty parameter are returned to the condition of 15 times iteration ago.

3. Trial on the creation of topology for requirement

In this study, a cantilever design famous as a bench mark problem for topology optimization is taken up. As shown in Fig. 6, shape and layout based on Kansei value of a subject are created as a design requirement under the physical conditions of maximizing stiffness and reducing initial layout's volume to 50% or less. A subject is two persons of the male in their twenties, and they are researcher (Subject A) of topology optimization and inexperienced person (Subject B), respectively. Additionally, initial density and initial penalty parameter for SIMP method were set to 0.5 and 3.0. And also, the termination conditions of this optimization process were carried out until a subject was satisfied.

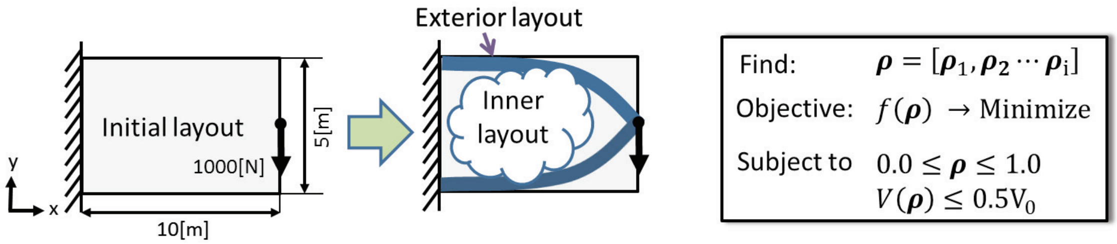
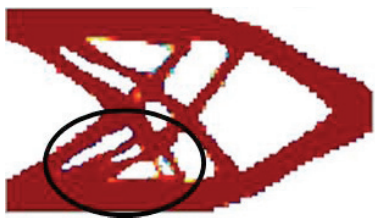


Fig. 6. Design definition for creating of topology requirements based on physical conditions

In Fig. 7, Creation results for topologies' requirements based on physical conditions are shown. Subject A created the topology for the objective of arranging many thin beams like a net-shape inside the target structure. And, Subject B created the topology for the objective of the target structure creating the beam of vertical asymmetry. From these topologies in Fig. 7, the result of Subject A was effected an object. On the other hand, the result of Subject B could not obtain an asymmetrical topology as for the overall structure. This reason is that the physical constraint worked strongly on the topology optimization process. However, the asymmetrical beams' distribution in the inner layout had occurred (see in circle area of Fig. 7(b)). Additionally, the mean compliance $f(\boldsymbol{\rho})$ and the volume $V(\boldsymbol{\rho})$ of physical conditions of two subjects' topologies were the equal values of 0.032 and 25.00, respectively.

(a) Subject A: Topology with an internal layout like a fine net shape



(b) Subject B: Topology with an internal layout consists of thick beams

Fig. 7. Creation result for topologies' requirement based on physical conditions

Next, Semantic Differential (SD) analysis was conducted based on the above consideration to the obtained topologies. The result of SD analysis is shown in Fig. 8. We confirmed that the big difference to the result of SD analysis of two subjects is seen. Subject A estimated that the obtained topology was satisfied although there was no newness. However, Subject B evaluated that obtained topology was new things, but was not satisfied. Furthermore, evaluation of SD analysis as "Comfort" became the low result. Since creation of the topology was greatly dependent on the topology optimization process, it is considered that topology was not able to be generated well. However, we consider that these evaluations are improvable by improving the introduction method of the brain waves parameter to topology creation.

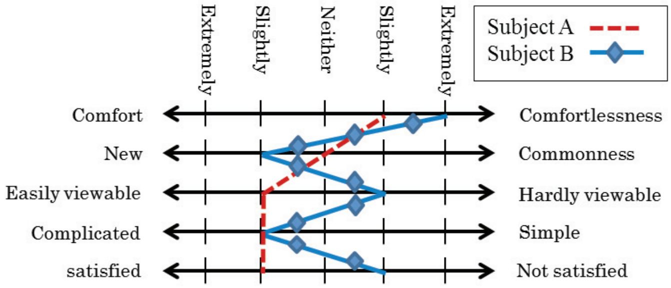


Fig. 8. Result of SD scale via SD analysis

4. Conclusion

In this paper, we proposed shape and layout understanding method which had not defined by ICSS to reflect the Kansei value. This proposal method distinguishes Kansei information from the obtained EEG data via BMI by using a discriminant function. Moreover, this information of discrimination is inputted into the SIMP method, and the topology optimization in consideration of Kansei value is performed. For verification of the usefulness of this method, the topology was created to define the requirement of cantilever design problem. Furthermore, in order to carry out the validation as requirement of the obtained topology, SD analysis was evaluated. As the result, we confirmed that the shape and the layout, i.e., the topology, suitable for the subject's objectives was able to be created. From the above mention, as a new support process of ICSS, It was shown that creation and requirement definition of the topology for the requirement which took Kansei value into consideration for the conceptual design of attractive products are possible. For the future, more improvement is advanced in order to give the flexibility of the topology creation in consideration of physical conditions for shape and layout understanding method.

References

1. The Ministry of Economy, Trade and Industry. *"KANSEI" Initiative - Suggestion of the fourth value axis* -. The Ministry of Economy, Trade and Industry; 2007. http://www.meti.go.jp/english/information/downloadfiles/PressRelease/080620KANSEI.pdf.
2. Altshuller, G. *Creativity as an Exact Science.* Translated by Williams A. Gordon and Breach Science Publishers; 1984.
3. Pahl G, Beitz W, Feldhusen J, Grote KH. *Engineering Design a systematic approach.* 3rd ed. Translated by Wallace K and Blessing L. Springer-Verlag; 2007.
4. Suh NP. *The Principles of Design*. Oxford University Press; 1990.
5. Kawamo K, Suga M. *Methodology of Creative Engineering Design – Principle of new Design and Manufacturing*. Yokendo; 2003 (in Japanese).
6. Mann DL. *Hands-on Systematic Innovation*. CREAX Press; 2002.
7. Sickfus Ed. *Unified Structured Inventive Thinking*. Ntelleck, LLC; 1997.
8. Brown T. *Design Thinking*. Harvard Business Review. Harvard Business Publishing; 2008.
9. Biomimicry Group. *Biomimicry Thinking*. Biomimicry 3.8 2014. http://biomimicry.net/about/biomimicry/biomimicry-designlens/biomimicry-thinking/; Reference date: 2015/03/20.
10. Chiu I, Salustri FA. Understanding Design Concept Identification. In: John S Gero, editor. *Design Computing and Cognition'12*. Springer; 2012.

11. Hasegawa H, Sonoda Y, Tsukamoto M, Sato Y. Creative and Inventive Design Support System: Systematic Approach and Evaluation using Quality Engineering. In: John S Gero, editor. *Design Computing and Cognition'10*. Springer; 2011, p. 229-249.
12. Sato A, Hasegawa H. Considering User's Kando for Conceptual Design on CDSS. *Proceedings of TRIZ Future Conference 2011*; 2011.
13. Norman DA. *Emotional Design –Why We Love (Or Hate) Everyday Things-*. Basic Books; 2005.
14. Katahira H. A consumer behavior model is from AIDMA to times of AIDEES. NikkeiBP; 2006:18. http://adweb.nikkeibp.co.jp/adweb/doc/LAP2006018.pdf (in Japanese).
15. Sato A, Hasegawa H. Proposal of a Conceptual Design Support System Considering User's Emotion. *Proceedings of JSME Design & Systems Division Conference 2011*. The Japan Society of Mechanical Engineers; 2011 (in Japanese).
16. Takezawa S, Yoshizaki Y, Utsumi K, Haseagwa H. Verification of Kando requirements in the Kando understanding support process using DOE and bioinstrumentation. *Procedia Computer Science.* Elsevier. 2014;35:1529-1538
17. Bensøe MP, Kikuchi N. Generation Optimal Topologies in Structural Design Using a Homogenization Method. *Computer Methods in Applied Mechanics and Engineering.* 1988;71:197-224.
18. Bensøe MP, Sigmund O. Material Interpolation Schemes in Topology Optimization. *Archive of Applied Mechanics*. Springer-Verlage. 1999;69:635-654
19. Nishiwaki S, Izui H, Kikuchi N. *Topology Optimization.* MARUZEN Publishing; 2013 (in Japanese).
20. Suzuki K, Kikuchi N. A Homogenization Method for Shape and Topology Optimization. *Computer Methods in Applied Mechanics and Engineering*. 1991;93:291-318.
21. Hasegawa H, Kawamo K. A Method for the Shape and Topology Optimization of Mechanical Structures by Using Genetic Algorithm: Layout Optimization Method by Adoption of Removal and Addition parameters of Elements as Chromosomes. *Transactions of the Japan Society of Mechanical Engineers* (*in Japanese*) 1995;61:581:A:183-190.
22. Otomori M, Yamada T, Izui K, Nishiwaki S. Topology Optimization Based on the Level Set Method Using Mathematical Programming. *Transactions of the Japan Society of Mechanical Engineers* (*in Japanese*) 2011;77:783:C:4001-4014.
23. Kawano T, Tsutsumi K. A development on the design idea generation support system for the facade of the office building Proposal of IDES (Interactive Differential Evolution with Score). *Transaction of Japan Society for Fuzzy Theory and Intelligent Informatics* (*in Japanese*) 2011;23:4:380-390.
24. Sato K, Numanyu M, Ujiie Y, Matsuoka Y. Comparison of the Emergent Design System and the Topology Optimization Method in a Structural Design Problem. *Transactions of the Japan Society of Mechanical Engineers* (*in Japanese*) 2010;76:769:C:2262-2267.
25. Touma M. *How is brain waves view read?* SHINKOUIGAKU Publishing; 2010 (in Japanese).
26. Michell AGM. The Limits of Economy of Material in Frame-structures. Phil. Mag 1904;6:8:589-597.